Phase-Preserving Amplitude Regeneration for RZ-DPSK Signals at 42.7 Gbit/s using Saturable Absorber

Quang Trung Le, Laurent Bramerie, Mathilde Gay, Sébastien Lobo, Michel Joindot, Jean-Claude Simon
Laboratoire Foton, CNRS/Université de Rennes 1 (UMR 6082), Enssat, BP 80518, 22305 Lannion cedex, France
quang-trung.le@enssat.fr

Hoang Trung Nguyen, Jean-Louis Oudar
LPN-CNRS, Route de Nozay, 91460 Marcoussis, France
jean-louis.oudar@lpn.cnrs.fr

Abstract: We experimentally evaluate a novel all-optical phase-preserving amplitude regeneration technique for RZ-DPSK signals using saturable absorber. The device's capacity for amplitude noise reduction, hence preventing from nonlinear phase noise accumulation is demonstrated at 42.7 Gbit/s.

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1. Introduction

Phase-shift keying (PSK) is considered as a candidate for high-capacity ultra-long-haul optical systems and has been widely studied. Such tendency has driven the search for all-optical PSK signal regeneration in order to improve the transmission quality in these systems.

The optical reach of an optical PSK transmission is mainly limited by the accumulation of linear and nonlinear phase noise. Linear phase noise results from amplified spontaneous emission (ASE) in optical amplifiers. Nonlinear phase noise results from intra- and interchannel nonlinearities such as self phase modulation (SPM) and cross phase modulation (XPM) that convert amplitude noise to phase noise, which is known as the Gordon-Mollenauer effect. By increasing the launched channel power, the impact of the linear phase noise induced by the accumulation of ASE could be reduced. However, the nonlinear phase noise becomes the most critical impairment factor.

Some recent works focused on phase noise reduction using interferometric phase-sensitive amplifier, an experimental demonstration of phase and amplitude regeneration has been reported [1]. And phase-regenerative amplification of a DPSK signal suffering only phase noise has been demonstrated in a combined Sagnac-SOA structure [2]. Moreover, phase-preserving amplitude regeneration can prevent the accumulation of nonlinear phase noise during transmission. Some techniques based on four-waves mixing in fiber [3] and on nonlinear optical loop amplifier [4] have been experimentally investigated.

Recently, a new generation of multiple-quantum-well semiconductor saturable absorber (SA) allowing power stabilization (called SA1) has been developed [5]. This new structure associated with the classical SA, which allows extinction ratio improvement, has shown good performance for all-optical amplitude-shift-keying signal regeneration [6, 7]. Thanks to its very thin structure (hundred-nanometer scale), the induced chirp because of the Kramers-Kronig relations is low, consequently phase variations of signal reflected on the SA chip is almost unchanged. In the context of return-to-zero differential phase-shift keying (RZ-DPSK) signal regeneration, the SA1 could be used for phase-preserving amplitude regeneration, hence preventing from nonlinear phase noise accumulation at high launched channel power. The device is fully passive, which requires neither Peltier cooler nor bias voltage, promising a compact and WDM-compatible solution [8].

In this paper, we report on a novel all-optical phase-preserving amplitude regeneration technique for RZ DPSK signals in which the amplitude fluctuations are reduced by the use of a SA1. Nonlinear phase noise reduction is studied with bit-error-rate (BER) and Q-factor measurements.

2. Experimental setup and principle of operation

In order to demonstrate the efficiency of the phase-preserving amplitude-regeneration function of the SA1, the experimental setup aims at generating a sufficient amount of nonlinear phase noise. To achieve that, the optical signal-to-noise ratio (OSNR) at the transmitter is degraded and a high channel power is used (fig. 1).

The transmitter (Tx) generates an 8-ps-pulse-width RZ-DPSK signal at 42.7 Gbit/s by using two Mach-Zehnder modulators, one for pulse carving and other for phase coding with push-pull setup. The signal wavelength is centered at 1550 nm. To achieve the OSNR degradation before the transmission, an ASE source followed by a 3-nm bandpass optical filter, centered on the working wavelength, and an optical attenuator (ATT) are used.

The regenerator stage is constituted by a reflective SA1. The signal is boosted to 6 dBm by an EDFA1 before being sent to the SA1 via an optical circulator (OC).

The transmission fiber is a non-zero dispersion-shifted fiber (NZ DSF with chromatic dispersion of 4.5 ps/km/nm at 1550 nm) followed by a dispersion-compensating fiber (DCF). An erbium-doped fiber amplifier (EDFA2) is used as a power booster to obtain signal power launched into the transmission fiber up to 18 dBm. And the EDFA3 compensates the residual lost. The pre-amplified RZ-DPSK receiver (Rx) consists of a fiber-based delay-line interferometer for demodulation of the DPSK signal and a balanced detector.

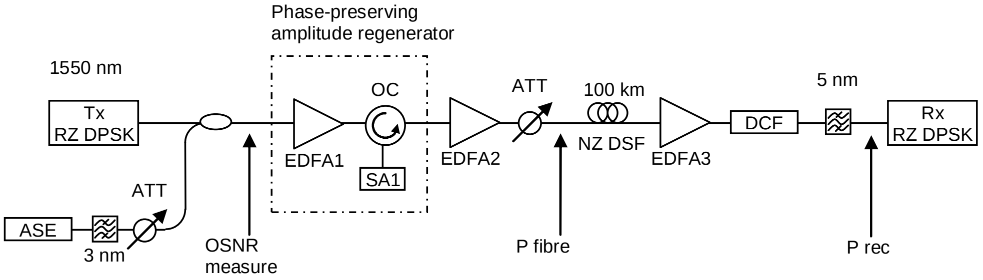

Fig. 1: Experimental setup.

3. Experimental results and discussion

The fig. 2 depicts the BER evolution versus the decision threshold at the receiver which is representative of noise distribution. The OSNR at the transmitter is degraded to 11.8 dB (measured over 1 nm), and the receiver input power is kept constant at 4 dBm. We have firstly demonstrated that the SA1 preserves the signal phase. The first curve (squares) corresponds to the signal issued directly from the transmitter with back-to-back measurement (B2B). And the second one (rhombi) corresponds to the signal after passing through the SA1 without fiber transmission. The system performance is only limited by linear phase noise due to OSNR degradation. As can be seen these two curves perfectly overlap, which means that the SA1 does not change the signal phase.

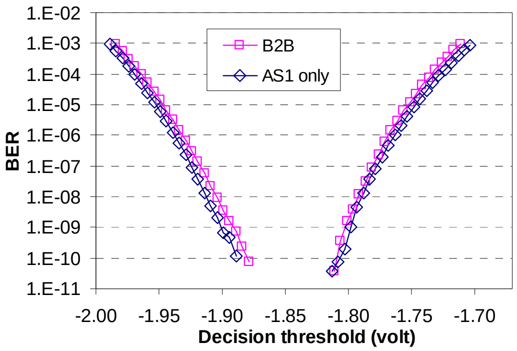

Fig. 2: BER evolutions versus decision threshold of the noise-loaded signals issued directly from the transmitter (squares) and after passing through the SA1 without 100-km transmission (rhombi).

Fig. 3 shows the measured BER versus the receiver input power for an OSNR at the transmitter of 13.8 dB. The square-mark curve is relative to the case of back-to-back (no transmission and without regeneration). The BER in this case is mainly limited by the linear phase noise induced by the ASE source, as shown by the power penalty compared to the B2B reference (OSNR of 30 dB: rhombi). The triangle-mark curve refers to a transmission case with 16 dBm launched power and without power limiter. A large power penalty is obtained and an error floor at BER of 5.10^{-10} appears owing to linear and nonlinear phase noise. When the SA1 based amplitude regenerator is used, the amplitude fluctuation is reduced, and nonlinear phase noise is partly removed. We obtain a considerable improvement of the BER for the same fiber launch power (circle-marked curve). Indeed, the BER curve with regeneration is brought close to the one limited only by linear phase noise. And the error floor disappears from the measurable range of BER. The efficiency of the regenerator is thus demonstrated.

Signal improvement by the SA1 is also investigated via Q-factor measurements. The Q-factor is evaluated using the Gaussian approximation. Fig. 4 shows the Q-factor versus signal power launched into the 100-km fiber span for an initial OSNR of 17.4 dB (full-mark curves) and 11.8 dB (empty-mark curves). The square-mark curves and the triangle-mark curves refer to the cases with and without SA1 respectively. When the OSNR equals to 17.4 dB, we observe clearly the Q-factor degradation due to nonlinear phase noise as the signal power exceeds 15 dBm. For longer transmission distances, the Q-factor curves are shifted to lower input power values since less launched power is needed for the same amount of total nonlinear phase noise in the system. And in the case with SA1 based regeneration, this degradation is reduced. For the signal powers less than 15 dBm, the nonlinear phase noise is negligible compared to the linear phase noise. As a consequence, the Q-factor cannot be improved by SA1 which preserves the linear phase noise accumulation. The greater the signal power, the more efficient the nonlinear effects, and thus the better the Q-factor improvement, thanks to the SA1. Q-factor is improved by 2 dB at 17.8 dBm signal power.

When the signal is more degraded (OSNR of 11.8 dB), the SA1 is effective for a launched power exceeding 13 dBm, compared to 15 dBm in the previous case. This could be explained by the fact that when more amplitude noise is added on the signal, the transfer of amplitude noise into phase noise by nonlinear effects becomes more effective at lower power signal, and thus the efficiency of the SA1 appears at lower signal power. A Q-factor improvement from 1 dB to 2 dB is obtained when the signal power increases from 14 dBm to 18 dBm in this case.

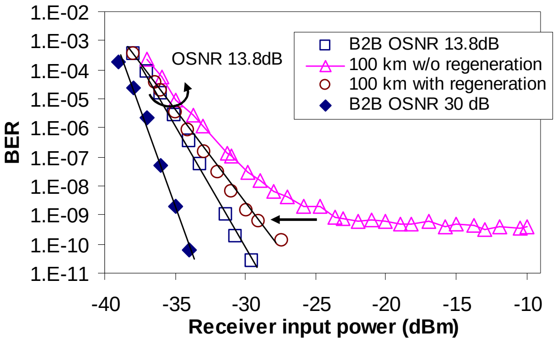

Fig. 3: The BER of the RZ DPSK signals versus receiver input power.

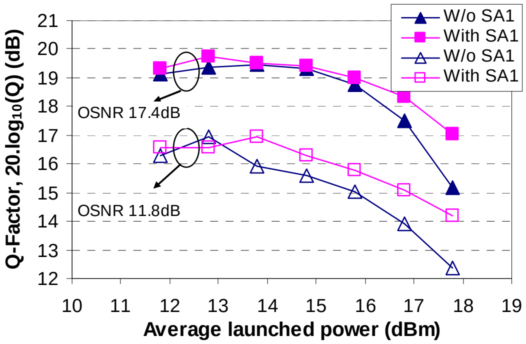

Fig. 4: Dependence of demodulated electrical Q-factor on the launched power into the transmission fiber.

4. Conclusions

We have reported for the first time the efficiency of the saturable absorber for the regeneration of high-power RZ-DPSK signals. The device reduces the amplitude fluctuations while preserving the signal phase, hence prevents the generation of nonlinear phase noise. The BER and Q-factor measurements showed the obtained signal quality improvement at high signal power where the nonlinear phase noise is significant. A Q-factor improvement up to 2 dB is obtained. The evaluation of device’s cascadability in a recirculating loop is a prospect for the future work.

5. References

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